ISA Journal of Engineering and Technology (ISAJET)

Homepage: https://isapublisher.com/isajet/
Email: office.isapublisher@gmail.com

Volume 2, Issue 1, Jan-Feb, 2025 ISSN: 3049-1843

Design and Construction of a Low-Cost Smart Solar-Powered Wheelchair

Vincent Andrew Akpan

Department of Biomedical Engineering, The Federal University of Technology, P.M.B. 704 Akure, Ondo State, Nigeria

Received: *01.03.2025*| ***Accepted:*** *30.03.2025*| ***Published:*** *24.06.2025*

***Corresponding Author:** Vincent Andrew Akpan

DOI: *10.5281/zenodo.15731943*

Abstract **Original Research Article**

Patients with disabilities and/or various physical limitations such as paraplegics, quadriplegics, stroke patients, the elderly and others have used wheelchairs to help them move around and meet their daily needs. In other cases, wheelchair mobility depends on another person or caregiver, handlebar-oriented wheelchairs which are supposed to be the solution for these people can cause various problems because the wheelchair operation require basic shoulder movement with additional energy and inconveniences. This paper presents the design and construction of an extremely low-cost smart solar-powered wheelchair. The wheelchair consist of six major parts, namely: (i) an Arduino Uno Microcontroller embedded system development board that controls the overall operation and functionality of the wheelchair; (ii) an integrated solar panel-based automatic 12-V two-way back-up stabilized power system to support both in/our door use of the wheelchair, (iii) L298N motor driver module for the wheelchair four-wheel manipulations; (iv) photocell circuit built around on light dependent resistor (LDR) with banks of light emitting diodes (LEDs) for illumination in dark environment; (v) a HC-SR04 ultrasonic sensor with a panic buzzer alarm for obstacle detection and alert; and (vi) an HC-06 Bluetooth module for the complete wireless control (speed and directions) of the wheelchair via a mobile application (App) on an android phone by the user. The designed and constructed low-cost smart solar-powered wheelchair has been tested, analyzed and its performances satisfy the aim and objectives of the project as well as satisfying the requirements of a standard wheelchair.

Keywords: Actuators, Embedded Systems, Integrated Automatic Power Supply System, Sensors, Smart Wheel Chair.

Citation: Akpan, V. A. (2025). Design and construction of a low-cost smart solar-powered wheelchair. *ISA Journal of Engineering and Technology (ISAJET), 2(1)*. ISSN: 3049-1843. [20-39]

1. INTRODUCTION

Recent statistics indicate that approximately 15% of the world's population, which translates to about 650 million people, suffers from some form of physical disability (Jones, 2019). Furthermore, individuals with physical limitations, including paraplegics, quadriplegics, stroke patients, and the elderly require assistive technology for mobility Traditional manual wheelchairs pose a challenge for individuals with limited hand or finger mobility, necessitating third-party assistance or manual control making them unsuitable for individuals with upper limbs impairments (Sahin and Yaziciolu, 2017).

To address these issues, electric motorized wheelchairs have been developed to provide a sustainable solution. These motorized wheelchairs are becoming increasingly prevalent and gaining popularity in both developed and developing countries (Jones, 2019). The incorporation of ultrasonic sensors in these electric wheelchairs enhances seamless mobility, maneuvering, collision and obstacle avoidance (Zhou *et al*., 2018). Furthermore, incorporating a solar panel for battery charging and optimization enhances the efficiency, reliability with low maintenance of these wheelchairs (Zhou et al., 2018). By providing a low-cost solution, the development of these electric wheelchairs aims to improve the mobility and quality of life for disabled or elderly individuals.

The revolution in automated power wheelchairs began after George Klein introduced them to World War II veterans in the mid-20th century (Hegde and Bhat, 2021). In 1986, Arizona State University developed an autonomous system that used machine vision to detect landmarks and a central wheelchair in a corridor (Shibata et al., 2001). TinMan CIPRO, USA, developed and marketed a number of joystick-controlled wheelchairs (Wang *et al*., 2020). At the same time, Japan's

Osaka University also developed an automatic wheelchair using image processing and some other algorithms (Hedge and Bhat, 2021). In the late 20th century, and the early 2000s, more automated wheelchair prototypes were developed (Wang et al., 2020). Since then, several technologies and models have been proposed and developed between 2000 and 2013 (Hedge and Bhat, 2021). The most reported technologies are eye-controlled motion signals (EOG), electroencephalogram (EEG) controlled, electromyography (EMG) controlled as well as tongue-controlled wheelchairs (Hedge and Bhat, 2021). However, the techniques developed require a portable sensor system and involve complex signal processing methods and additional computing devices mounted on the wheelchair (Hedge and Bhat, 2021). Some of the computing technologies are still at the research level (Wang *et al*., 2020). Since voice is the most common form of communication, some models have been developed to control wheelchairs using voice commands (Hedge and Bhat, 2021). In 2012, Kathirvelan and co-workers developed a system that uses verbal command to control a wheelchair with an FPGA-based speech processor controlled by LABVIEW (Kathirvelan *et al*., 2012). In 2015, Skarba and co-workers proposed a voice-controlled cloud-based wheelchair platform (Škraba *et al*., 2015). In Bangladesh, Azam and Islam proposed voice-controlled wheelchairs that used laptops to process voices (Azam and Islam, 2013). However, the weight limit of this model is not very suitable for elderly patients (Azam and Islam, 2013). The main limitations of the voice-controlled models are the need for an expensive speech processing unit and the design of a suitable motor control system that can support the load of an elderly adult (i.e., 60-80 kg) (Hedge and Bhat, 2021).

2. RELATED WORKS

Over the last two decades, nearly a dozen wheelchair-mounted assistive robotic manipulators have been developed, evaluated, and commercialized (Simpson, 2005; Singh, 2014; Goher, 2016; Gallagher *et al*., 2018). In addition, many institutions have conducted studies to evaluate the user experience and various user interfaces to enable wheelchair users to manipulate objects independently and efficiently as listed in Table 1. Despite these efforts, only few options are currently available in the market (Shittu, 2020).

Table 1(a): Basic review on smart wheelchairs reported in literature (Simpson, 2005)

S/N	Wheelchair	Publication Date Range	Description
1	Automated-Guided Wheelchair NEC Corporation, Japan	1992	Follow the tracks laid by the magnetic ferrite tape. Uses IR sensors to stop when obstacles are detected in its path.
2	Autonomous Wheelchair Arizona State University, U.S.A.	1986	Uses machine vision to detect landmarks and identify the middle wheelchair in an aisle.
3	CHARHM CDTA, Algeria	1996	Detects landmarks and corridors using central wheelchair machine vision. The chair autonomously navigates the environment based on internal maps and machine vision data
4	COACH French Atomic Energy Commission, France	1993	Avoids obstacles and follows walls. It is unclear how the active mode is selected.
5	NavChair University of Michigan, U.S.A.	1993-2000	Prevents the wheelchair from colliding with obstacles. Selects between multiple task-specific operating modes.
6	CWA (Manual) National University of Singapore, Singapore.	2002	Avoids obstacles and follows walls. It is unclear how the active mode is selected. Uses deceleration to keep wheelchair on track. The user can go out to avoid obstacles and control the speed of the wheelchair on tracks. A path can be defined by a graphical user interface or by inspection. Torque sensors on the push wheels detect user inputs. Small motorized wheels opt for standard manual wheelchair wheels.
7	CWA (Power) National University of Singapore, Singapore	2002	Uses deceleration to keep wheelchair on track. The user can go out to avoid obstacles and control the speed of the wheelchair on tracks. A path can be defined by a graphical user interface or by inspection. Torque sensors on the push wheels detect user inputs. Small motorized wheels apply power to standard manual wheelchair wheels Uses zero-calculation to keep the wheelchair on a stable path.
8	CCPWNS University of Notre Dame, U.S.A.	1994-2000	The user can automatically repeat the routes taught to the system by manually driving the wheelchair from the starting point to the end point. Uses machine vision to detect environmental landmarks. Obstacle Avoidance Mode.

9	Hephaestus TRAC Labs, U.S.A.	1999-2002	Provides obstacle avoidance. Compatible with many brands of wheelchairs and does not require modification of the power wheelchair underneath
10	INCH Yale University, U.S.A.	1989	A very early experiment using a small robot that rode like a wheelchair. Used to avoid sonar obstacles and falls.
11	INRO FH Ravensburg Weingarten, Germany	1998	Offers autonomous navigation (indoor and outdoor) and wheelchair escort
12	Intelligent Wheelchair System Osaka University, Japan	1998-2003	It has two cameras, one facing the user and the other forward. The user inputs head gestures into the system, which are interpreted by the inward-facing camera. The outward-facing camera tracks objects and allows the user to control the wheelchair with gestures after leaving the wheelchair. The reaction to user inputs (facial gestures) adapts to the environment of the wheelchair. The Chair automatically switches between modes (wall tracking, target tracking, obstacle avoidance) depending on the wheelchair's environment.

Table 1(b): Basic review on smart wheelchairs reported in literature (Simpson, 2005)

S/N	Wheelchair	Publication date range	Description
13	Intelligent Wheelchair University of Texas at Austin, U.S.A.	1998	Used as test bed for research into spatial representation and reasoning.
14	Luoson III National Chung Cheng University, Taiwan	1999-2000	Provides common navigational assistance (obstacle avoidance) with robust feedback joystick. Can also track, autonomous service robots to their destination
15	MAid RIAKP, Germany	1988-2003	It has two operating modes: Narrow Area Navigation (NAN) and Wide Area Navigation (WAN). In NAN, the system knows the initial position and direction of the target and navigates to the final position and direction. On the WAN, the system moves to the target, but also detects (and avoids) moving objects in the environment. Later, the ability to track moving objects was added.
16	Mister Ed IBM, U.S.A	1990	A robotic platform with a chair on it. Check the sub-architecture. Behavior groups were activated to achieve specific behaviors (passing a door, following a wall, following an object).
17	Mr. HURI Yonsei University, Korea	2002-2003	Uses machine vision to detect the user's facial movements. Can also accept EMG inputs (on the neck) or voice commands. Uses sonar to avoid obstacles.
18	NavChair University of Michigan, U.S.A.	1993-2000	Prevents the wheelchair from colliding with obstacles. Can automatically select between multiple task-specific operating modes.
19	NLPR Robotized Wheelchair Chinese Academy of Sciences, China	2000	Uses machine vision to detect landmarks for positioning. Offers several operating modes, including wall tracking, collision avoidance and autonomous navigation to a certain point on the map.
20	OMNI University at Hagen, Germany	1995-1999	The omnidirectional wheelchair offers a hierarchy of functionality: simple obstacle avoidance, task-specific operating mode (wall following, doorway) and autonomous navigation. The operating modes implemented and the mode switching mechanism are unclear
21	Orpheus National Technical University of Athens, Greece	1996-2002	Either navigates autonomously to position or provides obstacle avoidance while user navigates.
22	Phaeton Northeastern University, U.S.A.	1998	The user controls the wheelchair through a deictic user interface; the user selects an object on the video screen that the wheelchair is using and then the uses it as a target.
23	Siamo University of Alcala,	1999-2003	Used as a test bed for various input methods (voice, facial/head

	Spain		gestures, EOG). Provides obstacle avoidance. Uses machine vision to interpret the user's gaze to steer a wheelchair and detect landmarks. Uses both laser and infrared to detect falls. Uses a modular architecture based on commercially available building automation hardware. Enables wireless communication of the chair with device nodes in the environment.
24	SPAM AT Sciences, U.S.A.	2003-2004	Based on a manual wheelchair. Prevents the wheelchair from colliding with obstacles. Compatible with many brands of wheelchairs and requires no modification to the power wheelchair.

According to recent studies based on estimation on the number of people with disabilities in Nigeria, the 2011 World Report on Disability found that about 25 million Nigerians had at least one disability, while 3.6 million of them had very significant functional impairment (Umeh, 2016). According to the 2006 census of Nigeria, there were 3,253,169 people with disabilities, or 2.32 percent of the total population of 1.031,790 that year (Umeh, 2016). However, the Nigerian Center for Disabled Citizens called for a more accurate measurement of disability, as they believe that the census did not reflect the full extent of disability in Nigeria. By 2020, over 27 million Nigerians will be living with some form of disability who can benefit from using an electric wheelchair in the Nigeria population (Umeh, 2016).

Several studies have shown that both children and adults benefit significantly from independent mobility devices, including power wheelchairs, manual wheelchairs, scooters, and strollers (Srishti, 2015; Richard, 2014). According to Shahin and co-workers (Shahin *et al*., 2017), certain groups of people who could not fully benefit and adapt to social groups because they cannot easily access basic skill acquisition centers due to the lack of self-driving equipment. This affected paraplegics, who often go to the streets to beg for survival in most of the developing countries.

The purpose of the smart wheelchair is to help the disabled and the elderly by providing them with mobility options that would greatly improve their lives (Singh, 2014). The smart wheelchair expands the navigation capabilities of traditionally controlled manual and electric wheelchairs. Intelligent mobility systems can make life easier for many people with disabilities by increasing their mobility, especially for people with severe walking disabilities (Martin and Cooper, 2012). The self-driving system provides people with a significant sense of physical and psychological well-being and promotes a sense of self-confidence that can lead to improved self-esteem (Prasad, 2012).

Researchers have studied various methods of wheelchair control, and some have focused on the integration of hardware, software, and sensor technology to develop next-generation smart wheelchairs. For instance, Amiel and co-workers (Amiel *et al*., 2019) described the integration of hardware and software with sensor technology and computer processing to develop a next-generation smart wheelchair. He focused on the design of a computer cluster to test high-performance computing for intelligent wheelchair use and human interaction. A LabVIEW cluster was developed for real-time autonomous path planning and sensor data processing. Four small-factor computers were connected by Gigabit Ethernet LAN to form a computer cluster. Independent programs were distributed across the cluster to increase task parallelism and improve processing time efficiency (Amiel *et al*., 2019).

Hameed and co-workers (Hameed *et al*., 2021) designed and built a smart wheelchair with multiple control interfaces. The version of the smart wheelchair device was based on a traditional wheelchair currently available on the market and had similar electrical and mechanical developments. To improve user participation, the system included voice and gesture control interfaces in addition to a mobile app for wheelchair control (Hameed *et al*., 2021).

Another group of researchers (Leela *et al*., 2017) also designed a system where a disabled person gives his voice to an Android mobile phone, the output of the Android mobile phone is a voice command that is converted into text. The output of the mobile phone is given to the microcontroller, and the movement of the proposed system is controlled by the Bluetooth module using DC motors. This proposed system is a battery-powered wheelchair with DC motors. An ultrasonic sensor is also used to detect obstacles (Leela *et al*., 2017).

Furthermore, Rakhi and co-workers (Rakhi *et al*., 2013) designed and developed a system that allows the user to interact strongly with the wheelchair at the control and sensory level. Detection of dependent user using head movements and wheelchair integrated infrared sensor. The wheelchair can be driven by an accelerometer, and the head movement of this has the ability to avoid obstacles, which works on the principle of acceleration, the accelerometers whose power varies according to the acceleration applied to it. Using a simple formula, the amount of slope and the performance of the slope decides to move where the direction was calculated. Ultrasonic sensors were installed to detect walls/obstacles for free mobility (Rakhi *et al*., 2013). However, according to key researchers, manual wheelchairs did not provide a reliable and easy-to-use alternative for disabled users.

3. OVERVIEW OF THE PROPOSED LOW-COST SMART SOLAR POWERED WHEELCHAIR

The block diagram of the proposed low-cost smart solar-powered wheelchair is shown in Figure 1. The construction of a solar-powered Bluetooth-controlled wheelchair involves several key components, each of which must be carefully designed and integrated to create a functional and efficient mobility solution. The first component is the solar panel, which is typically mounted on the roof of the wheelchair. The solar panel is made up of a series of photovoltaic cells that capture and convert sunlight into electrical energy. The solar panel is connected to a charge controller, which regulates the flow of energy from the solar panel to the battery.

The second component is the battery, which is used to store the electrical energy generated by the solar panel. The battery is typically a deep-cycle battery that is designed to provide sustained power over an extended period. The battery is connected to the motor, control system, and Bluetooth module in the wheelchair, providing power to these components as needed.

The third component is the control system, which includes the microcontroller, motor, and other electronic components that regulate the wheelchair's movement. The microcontroller receives input from the Bluetooth module and translates it into commands for the motor, which moves the wheelchair accordingly. The control system also includes sensors that monitor the wheelchair's speed, direction, and other parameters, ensuring safe and efficient operation. The construction of a solar-powered Bluetooth-controlled wheelchair requires careful planning and integration of these components to create a functional and efficient mobility solution that meets the needs of wheelchair users.

The manual wheelchair with the names of the various standard parts is shown in Figure 2 (Rice *et al.*, 2012). The primary components of the electrical wheelchair framework consist of the seat and backrest, the footrest and largest, and the manage console. The seat and backrest are made from materials which might be durable, light-weight, and smooth to easy. The footrest and largest also are adjustable to deal with customers of various sizes, and are designed to provide aid and stability for the user's legs.

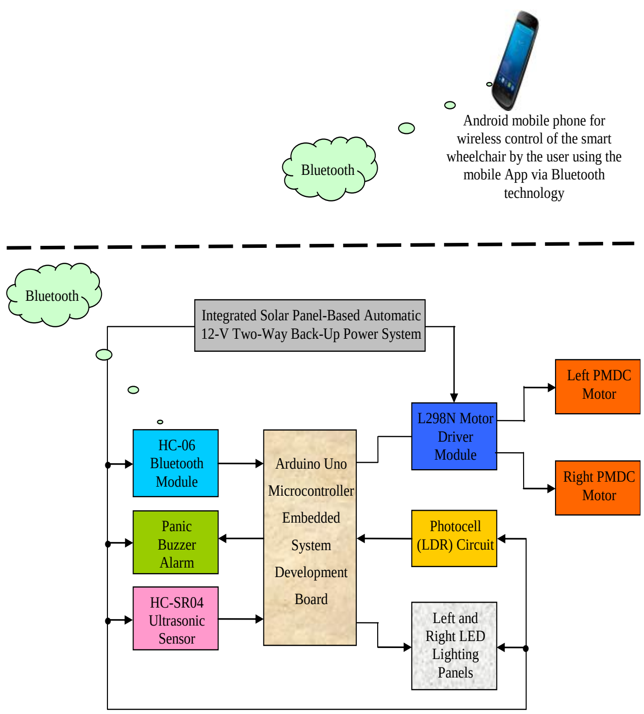


Figure 1: Block diagram of the low-cost smart solar-powered wheelchair.

Figure 2: A standard manual wheelchair with part names (Rice *et al.*, 2012).

The manage console is located on the armrest and includes the Bluetooth module or different manipulate mechanism for the person to operate the wheelchair. The Bluetooth module is commonly the number one control mechanism, permitting the user to control the velocity and path of the wheelchair. Some electric powered wheelchairs also have extra controls including buttons or switches that allow the user to operate and manage emergency cases.

The electrical wheelchair framework is likewise ready with wheels, a motor, and a battery electricity device, which paintings together to provide the propulsion and movement of the wheelchair. The wheels are generally made from a long lasting and light-weight fabric consisting of plastic or aluminium, and are designed to provide excellent traction and maneuverability. The electric motor is answerable for offering the electricity to drive the wheels, and its miles normally located inside the base of the wheelchair. The battery energy device is liable for presenting the power to the motor, and its miles typically located within the rear of the wheelchair.

The mechanical construction design of the electrical wheelchair framework is a crucial aspect of the capability and protection of the device. The dimensions of a standard wheelchair are shown in Figure 3 to simplify the proposed smart wheelchair design (Kamarul and Chou, 2014; Winter and Hotchkiss, 2025). The components of the framework are designed to provide a sturdy and sturdy structure that may support the load of the user and the electricity machine, while additionally imparting comfort and aid for the user. The manage console, wheels, motor, and battery strength device work together to offer propulsion and movement, and safety features along with brakes and seat belts offer added safety for the user.

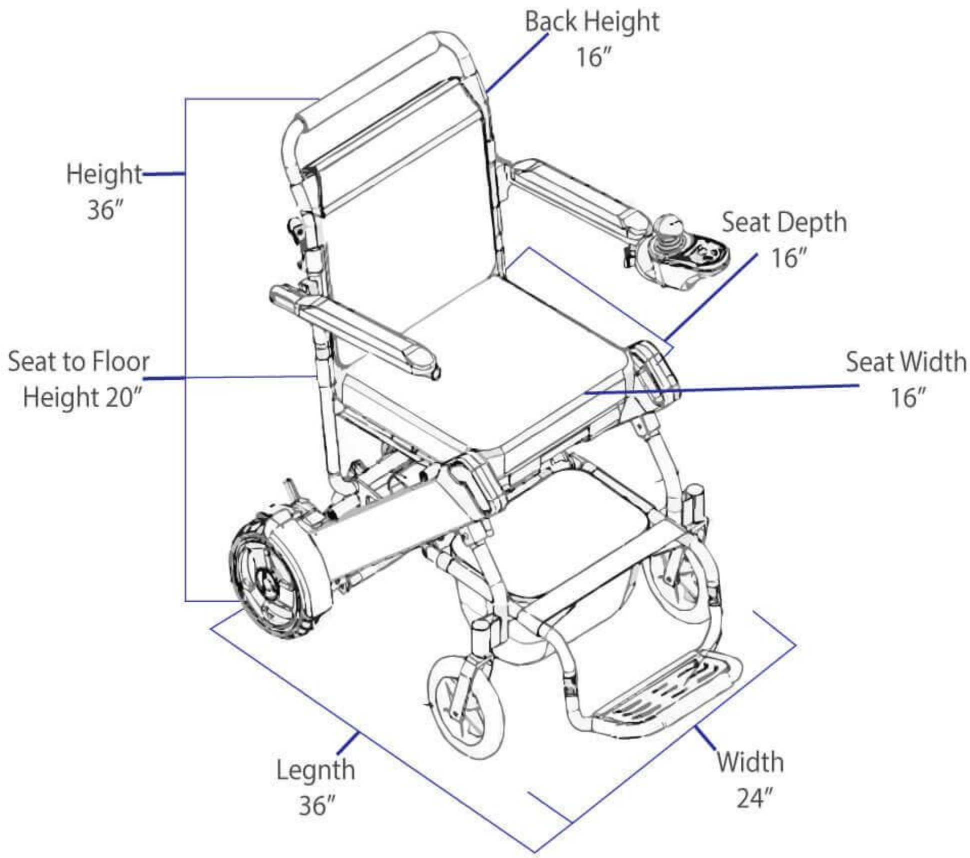


Figure 3: The dimensions of a standard manual wheelchair (Kamarul and Chou, 2014; Winter and Hotchkiss, 2025).

4. MATERIALS, DESIGN METHODOLOGY AND CONSTRUCTION OF THE LOW-COST SMART SOLAR-POWERED WHEELCHAIR

4.1 Materials

The materials required for the construction of the low-cost smart solar-powered wheelchair are: *(i)*Aluminium sheets, *(ii)* Galvanized pipe, *(iii)* Metallic wheels, *(iv)* Backrest seat, *(v)* Dunlop foot rest, *(vi)* Leather headrest, *(vii)* Ultrasonic sensor (HCSR04), *(viii)* Buzzer, *(ix)* DC battery (12-V), *(x)* Solar panel, *(x)* Two Stepper DC motors, *(xi)* Arduino Microcontroller, *(xii)* Motor driver (L298N), *(xiii)* Bluetooth module (HC 06), *(xiv)* Vero boards, *(xv)* LED light, *(xvi)* Photocell (Light Dependant Resistor, LDR), and *(xvii)* Switches and jumpers and connectors.

4.2 Mathematical Analysis of the Design

4.2.1 Total Expected Weight

The following design specifications were required to select a motor to effectively control the wheelchair.

Expected user weight range	= 90 kg.
Only the weight of the wheelchair	= 18 kg
The expected power requirement for the wheelchair control	= 10 kW.
The weight of the electric motor	= 1.8 kg.

The total Power TP 100XL brushless DC motor capable of producing 10.KW with weight 1.8 kg (Amiel *et al*., 2019).

Also, the motor is powered by a 12-V DC battery. The weight of the battery is ca = 0.0025 kg (it is insignificant) but a tolerance of 2 kg is added to the total weight. Thus, total expected weight (90 kg + 18 kg + 2 kg) = 110 kg

4.2.2 Calculating the Rolling Force

For aid rolling resistance in a wheelchair, "*roll factor*". This is a number determine empirically for different materials and can vary depending on wheel speed, wheel load and the material the wheel is in contact with.

Assuming a dynamic friction coefficient = 0.8 (which is mainly used for wheels and cement floor)

$$F = \mu R \tag{1}$$

where F = force required to overcome rolling friction, μ = coefficient of rolling friction and R = normal reaction.

$$R = mg + ma \tag{2}$$

If the wheel accelerates is at 1 ms^{-2}, then, $R = (110 \times 9.8)(110 \times 1) = 1188\,N$

$$\therefore F = 0.8 \times 1188 = 950\,N \tag{3}$$

Since the wheelchair has 2 wheels, each force has a separate motor required for each wheel:

Hence, $$F_{wheel} = \frac{950}{2} = 475\,N \tag{4}$$

Torque is the rotational force transferred from the motor to the load. Torque must be applied to move a rotating load, and a rotating load can be accelerated or decelerated by applying torque in the corresponding direction of rotation. In general, torque can be thought of as a measure of the turning force of an object rotating around an axis, and as such can be defined as the force multiplied by the distance from the axis of rotation. The wheel radius (R) is 0.28 m and the wheel torque is given by:

$$\tau = F \times 2\pi R \tag{5}$$

where τ is the torque in *Nm* and F is the force in N.

Thus,

$$\tau = 475 \times 2 \times 3.142 \times 0.28 = 836.12\,Nm \tag{6}$$

4.2.3 Correspondence to Initial Working Moment

There are three main torque to consider; release torque, operating torque and high inertia loads. Breaking torque is the torque required to move a stationary load. This is usually much higher than the torque required to turn the load, but it is only necessary to drive the load for a short time when the motors can often run with this increased torque on startup. Depending on the nature of the mechanism and the bearings used, the torque can be anywhere from 120% to 600% and greater than the torque.

The minimum Breakaway torque

= (1.2 × 836) + 836 = 1839 KNm (7)

The maximum Breakaway Torque

= (1.3 × 836) + 836 = 1922.8 KNm (8)

When choosing an engine, the free torque is taken into account.

Operating torque is the torque required to maintain the machine at normal rotational speeds. Operating torque can be calculated if the power requirement and motor speed are known. Thus,

$$\tau = \frac{30P}{\pi N} \tag{9}$$

where *N* is in number of revolution per minute (RPM), *P* is the power in kW and τ is the torque in kNm. When choosing a motor or frequency converter, in addition to the breaking and running torque, the inertia of the load must be considered. Unlike the release moment, a load with a high moment of inertia can take considerable time to accelerate or decelerate. As a result, the motor operates at increased torque for a longer period of time.

Revolution per Minute, (RPM) = 60×V/2×π×R
Assuming a velocity of $1ms^{-1}$, then
RPM = 60 × 1/ 2 × π × 0.28 = 34.1 Rev/min (10)

4.2.4 Smart Wheelchair Electric Motor Specifications

Using the breakaway torque, we have

$$\left.\begin{aligned} \text{Minimum power required } &= \frac{\tau_{\min}\times\pi\times RPM}{30} \\ &= \frac{1839\times 3.142\times 34}{30} \\ &= 65483.56W \\ &= 6.55kW \end{aligned}\right\} \quad (11)$$

$$\left.\begin{aligned} \text{Minimum power required } &= \frac{\tau_{\min}\times\pi\times RPM}{30} \\ &= \frac{1839\times 3.142\times 34}{30} \\ &= 65483.56W \\ &= 6.55kW \end{aligned}\right\} \quad (12)$$

$$\left.\begin{aligned} \text{Maximum power required } &= \frac{\tau_{\max}\times\pi\times RPM}{30} \\ &= \frac{1923\times 3.142\times 34}{30} \\ &= 6847.67W \\ &= 6.85kW \end{aligned}\right\} \quad (13)$$

Since the electric motor must have a capacity of between 6.55 - 6.85 kW is required; therefore, a battery with a voltage of 1.2 Volts with at least 1.6-amp hours (AH) will provide the power required by the motor.

4.3 The battery System

The system voltage is 9.0V Volts, and Power is 10watts, then the load current (I_L) is

$$I_L = \frac{Power}{Voltage} = \frac{7.0}{9.0} = 0.777\ A \quad (14)$$

It was estimated that the wheelchair shall be run for 8 hours continuously per day. Then the load current that provided for the wheelchair is computed using

$$\left.\begin{aligned} Load\ Current\,(I_L) &= 8\times 0.777\times 1.2 \\ &= 7.4592\ Ah/day \\ \therefore Load\ Current\,(I_L) &\approx 7.5\ Wh/day \end{aligned}\right\} \quad (15)$$

Assume 10% overall loss in the system,

$$Battery\ Size = 7.5\times 1.2 = 13\ Ah/day \quad (16)$$

Energy required for the motor

$$VI_L t = 13.05\times 9.0 = 117.5\ Wh/day \quad (17)$$

Therefore, 13.05 *Ah/day* with 9V Volt power is required for the optimal operation of the wheelchair system.

4.4 The Integrated Solar Panel-Based Back-Up Power Supply System

4.4.1 Overview

The integrated smart solar-powered system is to ensure the safe charging of the wheelchair's electric power source (battery) for optimal operation from two sources, namely: public power supply (electricity) and solar energy. The block diagram of the solar-based power supply system is shown in Figure 4. The solar-based power supply comprises of the solar panel shown in Figure 5 with its specifications in Table 2, the charge controller shown in Figure 6 (Morgan *et al.*, 2013). The block diagram of the complete automatic three-way backup power supply module is illustrated in Figure 7. The solar panel is shown in Figure 5 responsible for converting solar energy to electricity which is capable of charging the battery while the operational amplifier circuit, shown in Figure 6, built around LM358N regulates the charging process and prevents the battery from overcharging (Kalogirou, 2009; Ardila-Rey *et al*., 2017).

Table 2: Specifications of the Solar Panel.

S/N	Parameters	Standard values
1	Power (W)	100 Watts
2	Open Circuit Voltage (Voc)	21.6 V
3	Short circuit current (Isc)	6.46 A
4	Maximum Power Voltage (Vmp)	17.2 V
5	Maximum Power Current (Imp)	5.81A
6	Cell Type	Polycrystalline
7	Frame Type	Silver
8	Junction Box	Yes
9	Length	41.81”(1062mm)
10	Width	26.57”(675mm)
11	Depth	1.18” (30mm)
12	Weight	19.62 lb (8.9 Kg)
13	Connector	MC4 Pigtails 900mm

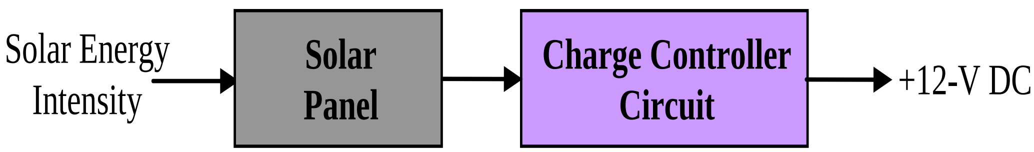


Figure 4: The block diagram of the solar-based power supply system


Figure 5: The solar panel (Morgan *et al*., 2013).

4.4.2 The Charge Controller

The charge controller (i.e. the automatic 15-V battery charger) is shown in Figure 6 (Akpan and Ewetumo, 2010). The charge controller designed for this smart wheelchair is a high performance charger with self regulating features. The main voltage regulator integrated circuit is the LM338 (IC1) whose output voltage is fixed at 15-V using the resistors values defined by Equation (11) and shown in Figure 6 through transistors Q1 and Q2 wired in the Darlington configuration mode (Franco, 1998; Jones, 1979):

$$V_{out} = 1.2\left(1 + \frac{R_3 + R_4}{R_1 + R_2}\right) \qquad (18)$$

Using Equation (18) with an expected V_{out} of 15.5-V and the resistor values in Figure 6, the computed value for R3 = 2.56 kΩ

The comparator sub-circuit is built around IC3 (LM308A) and transistor Q3 (Akpan and Ewetumo, 2010). This circuit uses the batteries voltage as a reference voltage to control the charging of the batteries by comparing the reference voltage (V_{ref}) against the charging voltage (V_{charge}). The batteries charging operation starts when the output of IC3 goes low (0-V), transistor Q3 turns OFF and transistor Q1 turns ON. When the batteries are fully charged, the output of IC3 goes high (+15-V), Q3 turns ON and Q1 turns OFF. The sensitivity of the comparison action is provided by the combined resistances of R10 and R11 which determines the ON-OFF switching of Q3.

The comparator sub-circuit is configured, as described in Coughlin and Driscoll (1989), in such a way that when V_{ref} is less than V_{charge}, the output of IC3 goes low (0-V), Q3 turns OFF and Q1 turns ON to charge the batteries with LED1 ON. When V_{ref} is equal to or greater than V_{charge}, the output of IC3 goes high (+15-V), Q3 turns ON and Q1 turns OFF to stop the charging process while LED2 turns ON indicating that the batteries are fully charged. The charging current is limited to 2 Amperes for smooth charging of the batteries. The charger switches ON and starts the charging process when the battery voltage drops below 10.5-V and switches OFF when the battery voltage reaches 15.5-V.

Also included within the battery charger circuit is a temperature compensation circuit built around LM334 (IC2) (Franco, 1998; Melling, 2004), which has been configured to switch OFF the charger when the internal temperature of the entire charge controller system is greater than 45ºC (although it can traditionally withstand a temperature of 70ºC) (Hall, 1989; Webb, 2005).

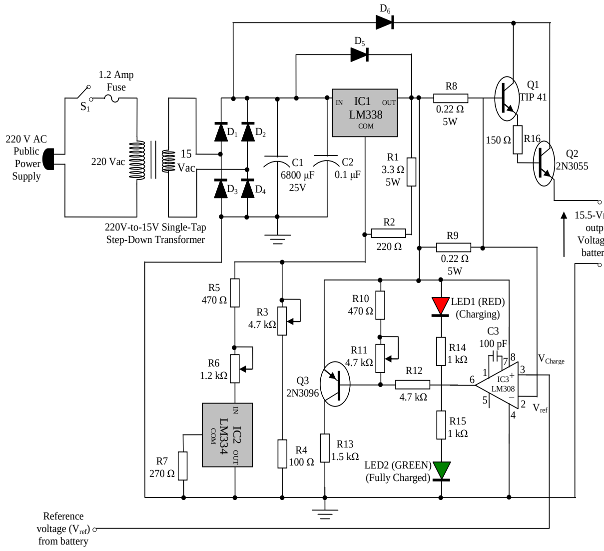


Figure 6: The charge controller circuit.

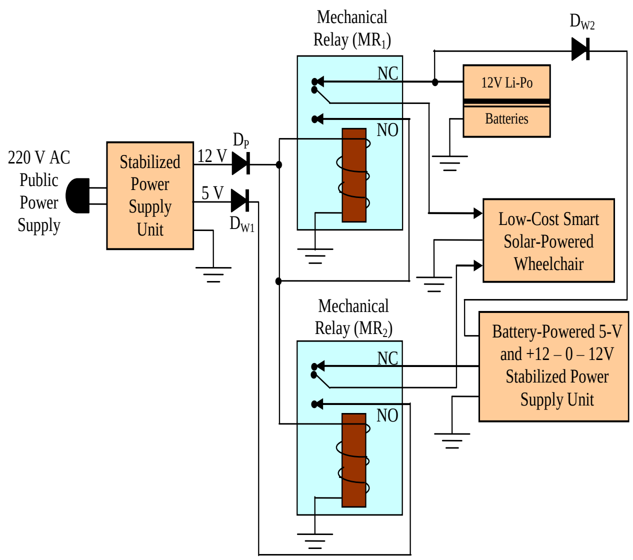


Figure 7: Block diagram of the proposed automatic two-way backup power supply module.

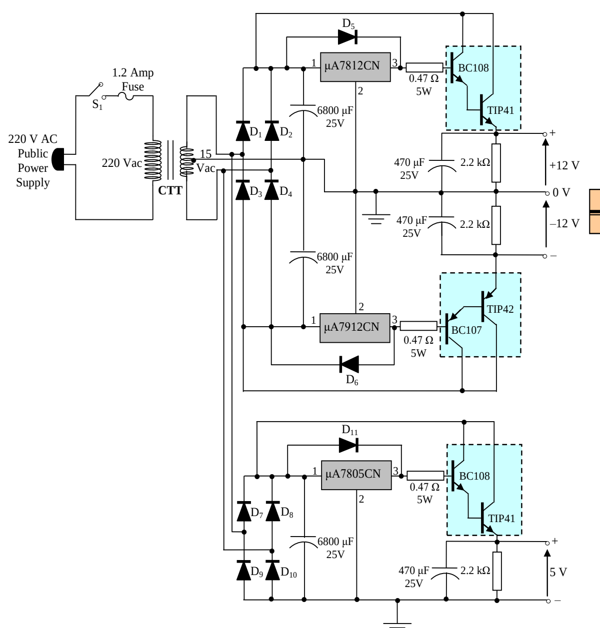


Figure 8: The multiple output stabilized power supply unit (SPSU).

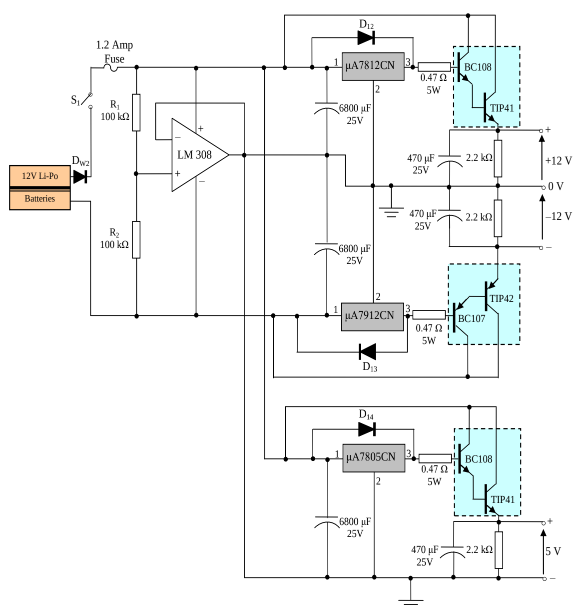


Figure 9: The circuit diagram of the proposed stabilized power supply unit.

4.4.3 Integrated Automatic Solar-Powered Stabilized Back-Up Power Supply System

The electric wheelchair is powered by both single and dual rail 12 V-DC power supply system using two 12-V Li-Po batteries connected in parallel for increased current delivery. The integrated automatic solar-powered stabilized back-up power supply system is supported by a solar panel with automatic charge controller discussed in the previous two sub-sections for sustained and continuous power supply to the smart wheelchair.

The Li-Po battery used for the smart wheelchair is rated at 12-V, 4-AH (ampere hours). The 4-AH Li-Po battery will sink 1-A of current from the battery and it is expected to take approximately 7 hours to completely discharge. The voltage regulator is liable for regulating and stabilizing the 12-V DC from the battery to 12-V DC for all the complete wheelchair circuits. The voltage regulator is built around the μA7812CN and μA7912CN while the 5-V regulator is built around μA7805CN integrated circuits (IC) shown in Figure 8.

As discussed in Section 3 using the block diagram of Figure 1, for the proper operation of the proposed low-cost smart solar-powered wheelchair, the Arduino UNO embedded system development board and other components require 5-V while the PMDC electric motor requires 12-V for optimal operation during maneuvering. On the other hand, the charge controller requires +12–0–12V dual rail power supply as shown in Figure 8.

The block diagram for the proposed automatic three-way backup solar-based power supply module supported with a 12-V rechargeable batteries, solar panel with charge controller as well as the battery-powered 5-V and +12–0–12V stabilized power supply units are shown in Figure 8 while the circuit diagrams of the multiple output (5-V and +12–0–12V) stabilized power supply unit (SPSU) and battery-powered 5-V SPSU are shown in Figure 9. As it can be seen in Figure 8, the automation of the power supply module is controlled by three mechanical relays MR_1, MR_2 and MR_3.

In the presence of public power supply, the SPSU of Figure 8 is activated and it delivers 12-V through diode D_P to MR_1 and 5-V through diode D_{W1} to MR_2 respectively to the automatic BMI machine for proper operation. Note that the 12-V from D_P: *1)* energizes MR_1 from normally-closed (NC) terminal to the normally-open (NO) terminal; and *2)* supplies stabilized 12-V that drives that smart wheelchair for proper operation.

On the other hand, in the absence of public power supply, the output terminal of MR_1 and MR_2 automatically returns to the NC terminals; and the Li-Po battery supplies 12-V directly to the smart wheelchair and to the battery-powered 5-V stabilized power supply unit for the proper operation of the smart wheelchair. In this way, the smart wheelchair can be used both for in-door and out-door situations.

4.5 The L298N Motor Driver

The L298N driver is an H-bridge development board which is used for the control of motors (Akpan and Eyefia, 2021a; Pelayo, 2025). This motor driver shown in Figure 10 is used to control the four Makeblock TT geared dc motors. The L298N motor driver enables the rotation of the motor in both clockwise and anti-clockwise direction as a result of the change in polarity which is dependent on HC-SR04 ultrasonic sensors. The L298N Motor Driver is used to drive the dc motors that work with up to 12 V dc. The L298N motor driver has two channels and each channel supports a 2 Ampere connection. This motor driver also can be used to drive stepper motors as well. The L298N motor driver module pins description is shown in Table 3 while the electrical specifications are shown in Table 4.

Table 3: Pin description of the L298N motor driver module.

Pin Symbols	Pin function description
GND	Power ground
VCC	Power supply
ENA	Enables PWM signal for motor1
IN 1	Enable Motor 1
IN 2	Enable Motor 1
IN 3	Enable Motor 2
IN 4	Enable Motor 2
ENB	Enables PWM signal for Motor 2

Table 4: Electrical Specifications of the L298N motor driver.

Electrical parameters	L298N motor driver module
Logical Voltage	5 V
Drive Voltage	5 V-35 V
Logical Current	0-36mA
Drive Current	2 A
Max Power	25W

The L298N Motor Driver Module used in this design shown in Figure 10 while the L298N motor driver module pin descriptions and the electrical specifications are shown in Tables 2 and 3 respectively. The L298N Motor driver module is a high power motor driver module for driving DC and Stepper motors. This module consists of an L298 motor driver IC and a 78M05 5V regulator. L298N Module can control 2 PMDC motors with directional and speed control.

The L298N motor driver module consists of an L298 motor driver IC, 78M05 Voltage Regulator, resistors, capacitors, power LED, 5-V jumper in an integrated circuit 78M05 Voltage regulator will be enabled only when the jumper is placed. When the power supply is less than or equal to 12-V, then the internal circuitry will be powered by the voltage regulator and the 5V pin can be used as an output pin to power the microcontroller. The jumper should not be placed when the power supply is greater than 12-V and separate 5-V should be given through 5-V terminal to power the internal circuitry.

ENA & ENB pins are speed control pins for Motor A and Motor B while IN1 and IN2, and IN3 and IN4 are direction control pins for Motor A and Motor B.

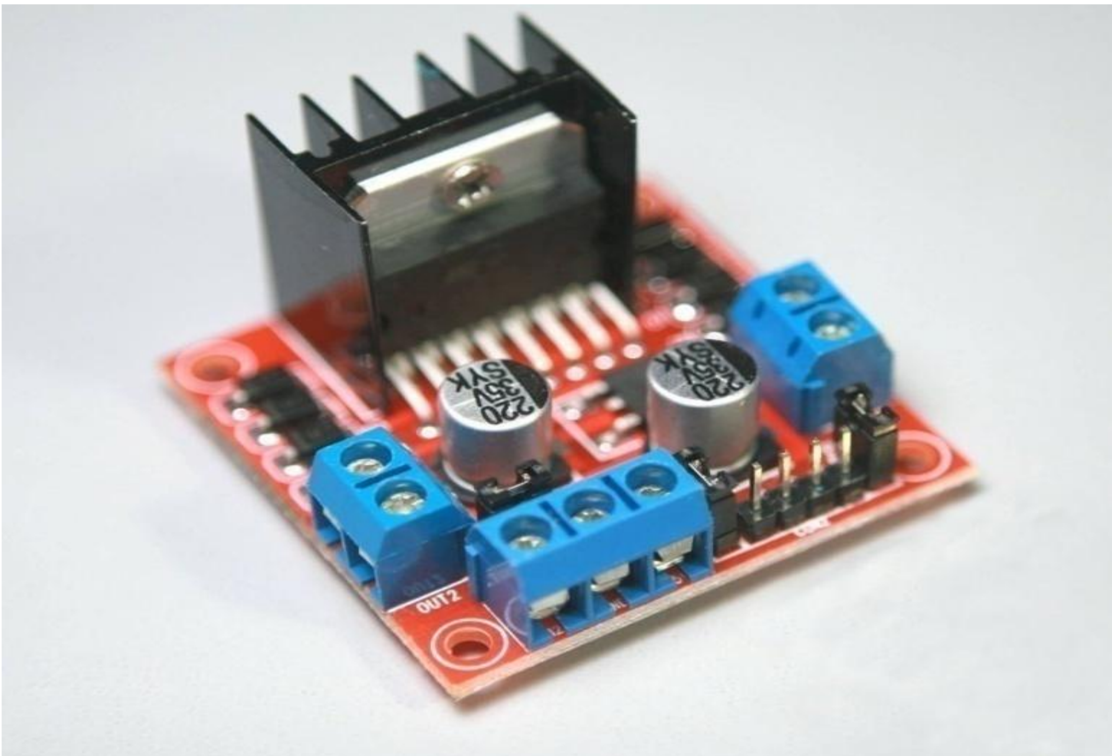


Figure 10: The L298N motor driver module (Pelayo, 2025).

4.6 The Wheelchair Motor Connections to the Arduino Uno Embedded System Development Board

The motor driver in an electric wheelchair is typically connected to the rotor of the motor through a gearbox and a drive shaft. The motor driver controls the speed and direction of the motor, which in turn drives the wheelchair. The motor used is a DC (direct current) motor, it rotates the shaft that is connected to the gearbox. The gearbox is used to reduce the speed of the motor and increase its torque, which is necessary for the wheelchair to be able to move with sufficient power.

The output shaft of the gearbox is connected to the drive shaft which extends to the rear wheels of the wheelchair. The drive shaft is responsible for transmitting the rotational motion of the motor to the wheels, which then move the wheelchair.

The connection of the motor to the Arduino board via the L298N motor is shown in Figure 11 and operates as follows:

(i). The controller can take up to 2 motors. One motor was plugged into the terminal labelled OUT1 and OUT2. The second motor into the terminal labelled OUT3 and OUT4;

(ii). The row of pins on the bottom right of the L298N controls the speed and direction of the motors. IN1 and IN2 control the direction of the motor connected to OUT1 and OUT2 while IN3 and IN4 control the direction of the motor connected to OUT3 and OUT4 which are respectively connected to pins 2, 3, 4, and 5 on the Arduino board; and

(iii). The L298N can be powered with up to 12V by plugging the power source into the pin on the L298N labeled “12V”. The pin labeled “5V” is a 5V output that was used to power the Arduino.

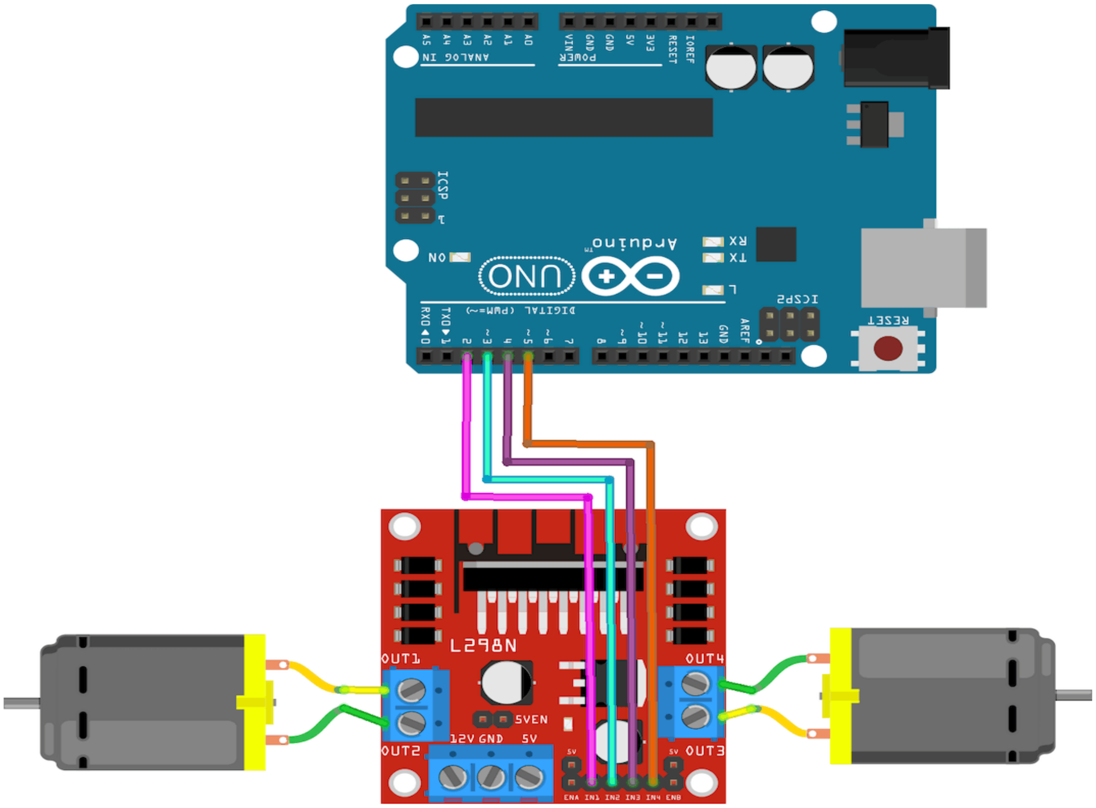


Figure 11: The motor connections to the Ardiuno Uno via L298N motor driver.

4.7 Integration of the Ultrasonic Sensor, Bluetooth Module, Photocell (Light Dependent Resistor, LDR) and the Panic Buzzer Alarm with Arduino Uno Embedded System Development Board

The primary applications of the sensors are to enhance optimal mobility of the wheelchair without any collision with obstacles. The four main sensor employed in the wheelchair design are: *(i)* Ultrasonic sensors, *(ii)* Bluetooth module, *(iii)* Photocell (light dependent resistor, LDR) and *(iv)* Panic buzzer alarm. The schematic diagram of the integration of the ultrasonic sensor, Bluetooth, and the panic buzzer alarm with the Arduino board is shown in Figure 12.

The HC-SR04 sensor was used as it can detect distance which has a range from 2cm to 400cm (Akpan and Eyefia, 2021a; Akpan and Eyefia, 2021b). The sensor is composed of two ultrasonic transducers. One is transmitter which outputs ultrasonic sound pulses and the other is receiver which listens for reflected waves. The sensor has 4 pins: the VCC pin was connected to the 5-V pin on the Arduino and the GND pin to the ground pin as well as the Trig and Echo pins were are connected to the digital pins 2 and 3 respectively on the Arduino board.

The HC-06 Bluetooth module has four pins which are all connected to the Arduino board as follows (Akpan *et al.*, 2022): *(i)* The VCC pin is where the module receives its input voltage and is thus connected to the 5-V pin on the Arduino; *(ii)*The GND on the module is the ground pin which connects to the ground pin on the Arduino. In other words, it is the reference point from where all the other voltages are measured; *(iii)* The RXD and TXD are the receiver and the transmitter pins respectively on the Bluetooth module. The Bluetooth module receives the serial data from the master device (android smartphone) through the RXD pin and then transfers that data to the Arduino using the TXD pin. The TXD pin on the module is connected directly to the RX pin on the Arduino whereas the RXD pin of the module is connected to the TX pin on the Arduino using a voltage divider circuit as the RXD on the module can only support voltage up to 3.3-V.

The photocell light dependent resistor (LDR) sensor is a special sensor whose operation depends on the intensity of light. The LDR is a resistor whose resistance changes as the amount of light falling on it changes. The resistance of the LDR decreases with an increase in the amount of light intensity falling on it and vice-versa. The photocell (LDR) control circuit is shown in Figure 13. With this property, the photocell (LDR) circuit is designed in such a way that it respond and automatically switch on the wheelchair light at night or anywhere the environment is dark. Whenever the wheelchair is used in a well illuminated environment, the wheelchair light goes off automatically which also help to conserve the durability of the power energy.

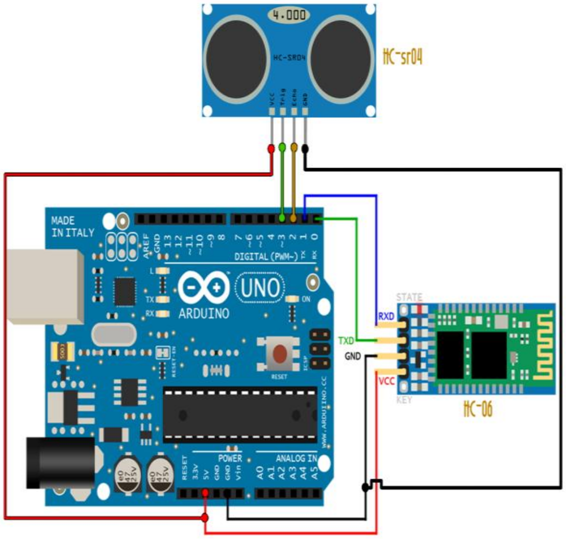


Figure 12: Integration of the ultrasonic sensor, Bluetooth module and the panic buzzer alarm with the Ardiuno Uno board.

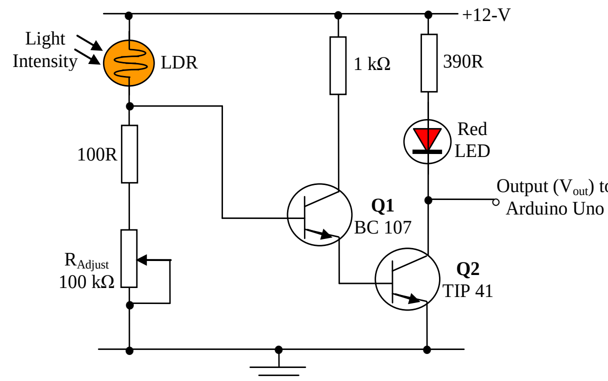


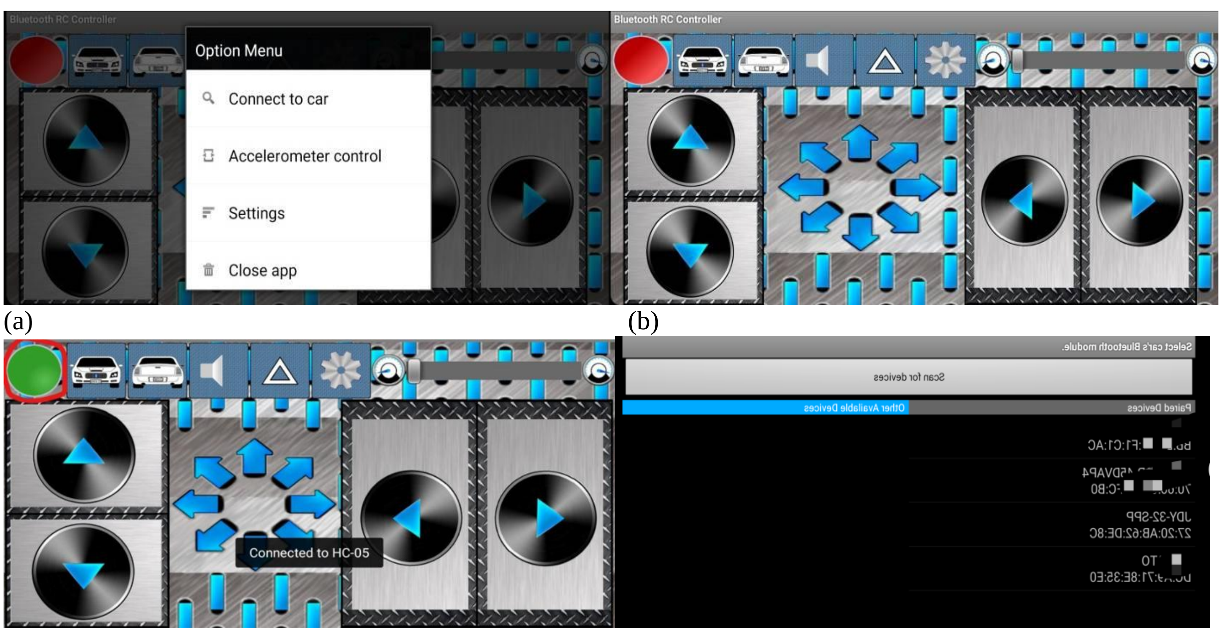
Figure 13: Photocell (LDR) control circuit.

4.8 Principles of Operation of the Smart Solar-Powered Wheelchair Using a Smartphone Interface App

The implementation of the solar-powered wheelchair is facilitated by embedding sensors to the wheelchair system. The major sensors used in the project implementation are ultrasonic sensor and photocell sensor. The ultrasonic sensor has a transmitter that transmits electromagnetic waves across the direction of the movement of the wheelchair and whenever there is an obstacle along the path of the wheelchair, the wave is reflected back by the obstacle and the sensor's receiver receives the wave and notify the microcontroller to energize the alarm system so that the user will be prevented from collision.

All the activities of the sensors are controlled by the microcontroller-based Arduino Uno embedded system which serves as the brain of the wheelchair operation. The microcontroller-based embedded system receives signals from the sensors and takes appropriate actuator actions and decisions accordingly.

In summary, the motor is located on the rear wheels of the wheelchair and is connected to the battery and a microcontroller that manages the speed and direction of the wheelchair using on the smart solar-powered wheelchair App based on the consoles shown in Figure 14.



(a) (b)

(c) (d)

Figure 14: The App connection processes for the smart solar-powered wheelchair control via an android smartphone.

When the user activates the Bluetooth connection with the "Bluetooth RC Controller App" which can be downloaded on play store, the controller receives the input signal and sends an electrical signal to the motor, which causes the wheels to turn and move the wheelchair in the desired direction. The speed of the wheelchair is controlled by adjusting the amount of power sent to the motor, which can be adjusted based on the user's preferences or needs.

The Li-Po rechargeable battery is located under the wheelchair seat and provides the power needed to operate the complete wheelchair circuitry. The battery is charged using solar energy or an external charger, which is connected to an electrical outlet. The designed and constructed smart solar-powered wheelchair is shown in Figure 15. The complete computer program embedded on the Arduino Uno embedded system development board for the operation of the smart solar-powered wheelchair is given in APPENDIX I.

Figure 15: The designed and constructed low-cost smart solar-powered wheelchair.

5. RESULTS

The testing of the smart solar-powered electronic wheelchair includes several steps to ensure optimal functionality. The first stage of testing entails verification of the circuitry, which includes examining the wiring and connections for mistakes or faults. This is accompanied by the checking the acceleration and deceleration of the wheelchair. The solar panel and battery gadget are then checked to ensure they are charging and discharging correctly.

The second level of testing includes real-world scenarios in which the wheelchair is tested in/out door environments with varying weather condition. That is to ensure that the sun panel can generate sufficient energy to satisfy the wheelchair strength requirements. In case of raining seasons, the integration of power pack have been ensured to provide adequate and continuous means of power compensation. Additionally, the wheelchair's digital wireless control via the Bluetooth was tested to ensure the wheelchair performs appropriately. Standard, the testing methodology for a sun-based totally electronic wheelchair requires a complete testing method to ensure that it functions optimally and can offer the consumer a reliable and comfortable mobility solution.

5.1 Users' Weight and Wheelchairs Operational Time

The data shown in Table 5 was obtained with respect to individual weight which defines the operational time of the wheelchair. Table 5 is based on a typical range of battery capacity and weight for a standard electric wheelchair, and assumes a constant speed and driving conditions as controlled wirelessly through the Bluetooth module using the android mobile App.

Table 5: Wheelchair user's weights over operational time in hours

Users	Weight (Kg)	Operational time (Hours)
1	15	12.0
2	21	11.0
3	22	11.0
4	25	10.5
5	27	10.0
6	30	9.5
7	36	9.0
8	39	8.5
9	42	8.0
10	46	8.0
11	49	7.5
12	50	7.5
13	56	7.0
14	58	6.5
15	62	6.5
16	64	6.5
17	67	6.0
18	68	6.0
19	70	5.5
20	70	5.5

5.2 Solar Energy Intensity versus the Wheelchairs Battery Charging Time

The data shown in Table 6 shows the actual relationship between light intensity and charging time for the smart solar-powered wheelchair may vary based on a variety of factors such as the efficiency of the solar panels, the capacity of the battery, and the amount of energy required to power the wheelchair.

Table 6: Solar energy intensity versus the wheelchair battery charging time in hours

S/N	Sunlight Intensity (Lux)	Charging Time (Hours)
1	500	2.5
2	1000	2.0
3	1500	1.5
4	2000	1.0
5	2500	0.8
6	3000	0.7
7	3500	0.6
8	4000	0.5
9	4500	0.4
10	5000	0.3

5.3 Current-Voltage Relationship of the Smart Solar-Powered Wheelchairs Battery Charging System

The results of Table 7 show that the voltage-current relationship of the smart solar-powered wheelchair battery charging capability where the voltage is directly proportional to the charging current. Therefore, the rate of charging of the power pack depends on the level of voltage supplied by the utility service provider.

Table 7: Current-Voltage relationship of the power pack charging system

S/N	Voltage (V)	Current (I)
1	3.0	1.2
2	4.0	1.4
3	5.0	1.6
4	6.0	1.8
5	7.0	2.0
6	8.0	2.2
7	9.0	2.4
8	10.0	2.6
9	11.0	2.8
10	12.0	3.0

6. DISCUSSIONS, CONCLUSION AND FUTURE DIRECTION

6.1 Discussions

The smart solar-powered wheelchair has been evaluated based on several criterions as briefly discussed in the following:

(i) User Satisfaction: User satisfaction was assessed through surveys and interviews with users of the wheelchair. The results showed that users were highly satisfied with the performance of the wheelchair, particularly in regards to its ease of use, reliability, and safety features.

(ii) Performance: The performance of the solar powered smart wheelchair was evaluated in terms of its ability to drive the wheelchair effectively, avoid obstacles, and respond accurately to inputs from the user. The results showed that the system was highly effective in these areas, providing a reliable and safe experience for the user.

(iii) Energy efficiency: The energy efficiency of the solar powered smart wheelchair was evaluated in terms of its ability to effectively use the energy provided by the solar panel and battery. The results showed that the system was highly energy efficient, providing extended use without the need for frequent battery recharging. The testing and evaluation of the solar powered smart wheelchair showed that it is a highly effective, reliable, and safe system that provides significant benefits for disabled users.

6.2 Conclusion

The solar-powered smart wheelchair has been successfully designed and implemented to increase mobility for individuals with physical disabilities in a sustainable and eco-friendly manner, while keeping costs low. This innovative solution addresses the limitations of conventional electric wheelchairs and uses solar energy to charge its battery, with intelligent technology enhancing its functionality.

The development of the solar-powered smart wheelchair involved several stages, beginning with research and selection of appropriate components for the design. The wheelchair chassis was built using a combination of steel and plastic materials, a solar panel and battery were integrated into the design. Smart technology was also incorporated to improve control and functionality.

Compared to conventional electric wheelchairs, the solar-powered version has several advantages. It is environmentally friendly, utilizing renewable energy sources to power its battery, and the smart technology allows for easy control and use. Additionally, the low cost of the wheelchair makes it an affordable option for individuals with disabilities from low-income families.

Overall, the design and implementation of the smart solar-powered smart wheelchair for individuals with disabilities is a significant achievement that provides an affordable, sustainable, and environmentally friendly mobility solution. By implementing the aforementioned recommendations, the solar-powered smart wheelchair has the potential to revolutionize the mobility industry for people with disabilities.

Conclusively, the successful design and implementation of the solar-powered smart wheelchair for disadvantaged individuals provides a sustainable and cost-effective solution to mobility. With its many advantages and potential for further development, this innovative wheelchair has the potential to greatly improve the lives of people with disabilities.

APPENDIX I: Software for the implementation of the low-cost smart solar-powered wheelchair

```
intmotorRightA = 8;    //Right Motor-clockwise
intmotorRightB = 9;    //Right Motor-anticlockwise
intmotorLeftA = 11;   //Left Motor-clockwise
intmotorLeftB = 10;   //Left Motor-clockwise
int trigPin1   = 12;     // Trig Pin
int echoPin1 = 13;     // Echo Pin
int light = 5;
long duration1;
int distance1;
char bt = 0;           //Bluetooth Control
int trigPin2 = 7;       // Trig Pin
int echoPin2 = 6;       // Echo Pin
long duration2;
int distance2;
int buzzer = 4;
intpushButton = 3;
void setup()
{
pinMode(motorRightA, OUTPUT);
pinMode(motorRightB, OUTPUT);
pinMode(motorRightB, OUTPUT);
pinMode(motorLeftB, OUTPUT);
pinMode(trigPin1, OUTPUT);
pinMode(echoPin1, INPUT);
pinMode(trigPin2, OUTPUT);
pinMode(echoPin2, INPUT);
pinMode(light, OUTPUT);
pinMode(buzzer, OUTPUT);
pinMode(pushButton, INPUT_PULLUP);
Serial.begin(9600);
}
void loop()
{
  //Light On Off
lightOnOff();
  //Panic Button
panicSound();

  //  Right
digitalWrite(trigPin1, LOW);
delayMicroseconds(2);
  // Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin1, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin1, LOW);
  // Reads the echoPin, returns the sound wave travel time in microseconds
  duration1 = pulseIn(echoPin1, HIGH);
  // Calculating the distance
  distance1 = duration1 * 0.034 / 2;
  // Prints the distance on the Serial Monitor
Serial.print("Distance: ");
Serial.println(distance1);
// Left
digitalWrite(trigPin2, LOW);
delayMicroseconds(2);
  // Sets the trigPin on HIGH state for 10 micro seconds
digitalWrite(trigPin2, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin2, LOW);
  // Reads the echoPin, returns the sound wave travel time in microseconds
  duration2 = pulseIn(echoPin2, HIGH);
  // Calculating the distance
  distance2 = duration2 * 0.034 / 2;
  // Prints the distance on the Serial Monitor
Serial.print("Distance: ");
Serial.println(distance2);
  if (distance1 <= 20 || distance2 <= 20)
{
    //Stop Wheel Chair
digitalWrite(motorRightA, LOW);
digitalWrite(motorRightB, LOW);
digitalWrite(motorLeftA, LOW);
digitalWrite(motorLeftB, LOW);
control();
  }
  else {
control(); // Call All the Control
  }
}

// All the Controls of the Wheel Chair
void control() {
  if (Serial.available() > 0)
  {
bt = Serial.read();
    if (bt == 'F')       //move forwards
    {
digitalWrite(motorRightA, HIGH);
digitalWrite(motorLeftA,  HIGH);
    }
    else if (bt == 'B')             //move backwards
    {
digitalWrite(motorRightB, HIGH);
digitalWrite(motorLeftB, HIGH);
    }
    else if (bt == 'S')     //stop!
    {
digitalWrite(motorRightA, LOW);
digitalWrite(motorRightB, LOW);
digitalWrite(motorLeftA, LOW);
digitalWrite(motorLeftB, LOW);
    }
    else if (bt == 'R')    //right
    {
digitalWrite(motorRightA, LOW);
digitalWrite(motorRightB, LOW);
digitalWrite(motorLeftA, HIGH);
digitalWrite(motorLeftB, LOW);
    }
    else if (bt == 'L')     //left
    {
digitalWrite(motorRightA, HIGH);
digitalWrite(motorRightB, LOW);
digitalWrite(motorLeftA, LOW);
digitalWrite(motorLeftB, LOW);

    }
    else if (bt == 'I')    //forward right
    {
digitalWrite(motorRightA, HIGH);
digitalWrite(motorRightB, LOW);
digitalWrite(motorLeftA, LOW);
digitalWrite(motorLeftB, HIGH);
    }
    else if (bt == 'G')    //forward left
    {
digitalWrite(motorRightA, LOW);
digitalWrite(motorRightB, HIGH);
digitalWrite(motorLeftA, HIGH);
digitalWrite(motorLeftB, LOW);
    }
  }
}
void lightOnOff() {

  if (bt == 'O') {
digitalWrite(light, HIGH);
  }
  else if (bt == 'o') {
digitalWrite(light, LOW);
  }
}
void panicSound() {
intval = digitalRead(pushButton);
  if (val == LOW) {
digitalWrite(buzzer, HIGH);
  } else {
digitalWrite(buzzer, LOW);
  }
}
```

6.3 Future Directions

As a future direction, the design of the seating system, backrest, footrest, armrests, and controls, as well as the adjustment of the chair fits the user's body size and posture can be improved upon for ergonomic and anthropometric enhancements. The goal is to reduce the risk of injury and discomfort, increase user independence and mobility, and improve overall quality of life for wheelchair users. Innovative ergonomic features such as adjustable backrests, height-adjustable armrests, and pressure-relieving cushions is recommended.

Acknowledgement

The author wish to acknowledge Miss Damilola Esther Odewuyi, Mr. Mujeeb Adekunle Oduola, and Miss Tolulope Omolade Idowu of the Department of Biomedical Engineering, FUTA for their technical and financial supports as well as their criticism, testing and analysis that lead to the timely completion of this project.

REFERENCES

Akpan, V. A. and Ewetumo, T. (2010) "Design, Development and Construction of a Low Cost Automatic 2 KVA Inverter System", Global Journal of Pure and Applied Sciences, 16(1), 141 – 149.

Akpan, V. A. and Eyefia, S. A. (2021a) "Autonomous Vehicle with Machine Vision and Integrated Sensor Suit Based on Internet-of-Things Technologies", International Journal of Electronics Engineering and Computer Science, 6(3), 18 – 30. [Off-Shore] [Contribution: 60%] Available [Online]: HYPERLINK "http://www.aiscience.org/journal/paperInfo/ijeecs?paperId=4702" http://www.aiscience.org/journal/paperInfo/ijeecs?paperId=4702 .

Akpan, V. A. and Eyefia, S. A. (2021b) "Development of an Enhanced Obstacle Detection System Using Arduino Mega 2560", African Journal of Computing and ICT, 14(2), 1 – 12. Available [Online]: HYPERLINK "https://afrjcict.net/wp-content/uploads/2017/08/Vol142Sep21pap1pagenumb.pdf" https://afrjcict.net/wp-content/uploads/2017/08/Vol142Sep21pap1pagenumb.pdf .

Akpan, V. A., Agbogun, J. B. and Olatunji, D. A. (2022) "The Development of an Integrated Wireless Security Surveillance System Based on Internet-of-Things Technologies", International Journal of Internet of Things, 10(1), 1 – 21. Available [Online]: HYPERLINK "http://article.sapub.org/10.5923.j.ijit.20221001.01.html" http://article.sapub.org/10.5923.j.ijit.20221001.01.html .

Amiel, I., Kadosh, S., Sason, I. and Fischer, A. (2019) "A next-generation smart wheelchair for intelligent human-robotic interaction: A review", IEEE Access, 7, 81000 – 81013.

Ardila-Rey, J. A., Monje-Garcia, M. and Alcaide-Moreno, B. (2017) "Solar-powered electric wheelchairs: A review", Renewable and Sustainable Energy Reviews, 67, 521 – 530.

Azam, O. and Islam, M. T. (2013) "Voice-controlled wheelchair. Journal of Medical Engineering & Technology", 37(5), 342 – 347.

Coughlin, R. F. and Driscoll, F. F. (1989) "Operational Amplifiers and Linear Integrated Circuits", 4th Ed., Prentice-Hall International Edition, New Delhi, India, pp. 215 – 226.

Franco, S. (1998) "Design with Operational Amplifier and Analog Integrated Circuits", 2nd Ed., McGraw-Hill Books Company, Singapore, pp. 43 – 441.

Gallagher, D.D., Dickerhof, M. and Stienen, A. H. (2018) "Solar-powered wheelchairs for people with disabilities in developing countries", International Journal of Environmental Science and Technology, 15(6), 1293 – 1302.

Goher, K. M. (2016) "Design and construction of reconfigurable wheelchair for children with disabilities", International Journal of Rehabilitation Research, 39(1), 74 – 77.

Hall, D. V. (1989) "Digital Circuits and Systems", McGraw–Hill, Singapore, pp. 435 – 557.

Hameed, M., Nabil, M., Bashir, A. K. and Fong, K. W. (2021) "Development of a smart wheelchair with multiple control interfaces", IEEE Access, 9, 107682 – 107691.

Hegde, A. and Bhat, S. K. (2021) "A review of assistive technologies for mobility", Journal of Medical Systems, 45(4), 1 – 18.

Jones, M. H. (1979) "A Practical Introduction to Electronic Circuits", CambridgeUniversity Press, London, pp. 167 – 452.

Jones,E. (2019) "Wheelchair Use and Accessibility in Developing Countries", Frontiers in Public Health, 7(33), 1 – 15.

Kalogirou, S. (2009) "Solar Energy Engineering: Processes and Systems, Academic press, Elsevier, U.S.A., pp. 1 – 756.

Kamarul, T. and Chou, T. C. (2014) "Biomechanical analysis of manual wheelchair propulsion by various wheelchair users with different disabilities: a review", Clinical biomechanics, 29(1), 1 – 7.

Kathirvelan, J., Parthasarathy, K. and Renganathan, S. (2012) "Voice controlled wheelchair for disabled", In 2012 IEEE International Conference on Communication Systems and Network Technologies, pp. 685 – 689, doi: 10.1109/CSNT.2012.106.

Leela, V. Sahiti, K. and Mahesh, T. (2017) "Voice-controlled smart wheelchair with obstacle avoidance using Android mobile", International Journal of Engineering and Technology, 9(4), 3059 – 3064.

Martin, J. I. and Cooper, R. A. (2012) "Driving forces in mobility assistive technology", Disability and Rehabilitation: Assistive Technology, 7(2), 85 – 90.

Melling, T. (2004) "RS Catalogue. Enigma Corporation Limited", East Sussex, U.K, pp. 989 – 1882, 2004.

Morgan, H. Jeska, L. and Leonard, D. (2013) "The expansion of active regions into the extended solar corona", The Astrophysical Journal Supplement Series, 206(19), 1 – 10.

Pelayo, R. (2025) How to used L298N motor driver. Accessed 18 February, 2025 from https://teachmemicro.com/use-l298n-motor-driver.

Prasad, R. (2012) “Smart wheelchair: A review”, Journal of Rehabilitation and Assistive Technologies Engineering, 4, 1 – 11.

Rakhi, P. A., Sharanya, P. M., Krishnan, A. V. and Ananthanarayanan, V. (2013) “Smart wheelchair using head movements and infrared sensor”, International Journal of Advanced Research in Computer Science and Software Engineering, 3(12), 109 – 112.

Rice, L. A. Smith, I. and Kelleher, A. (2012) “Powered mobility and cognition: How does it affect a toddler's spatial awareness?” Infant and Child Development, 21(6), 610 – 620. Available [Online]: HYPERLINK "https://doi.org/10.1002/icd.1788" https://doi.org/10.1002/icd.1788 .

Richard, M. J. (2014) “Physical disability, independent mobility, and social interaction in a community sample of aged persons”, Journal of Gerontology, 49(3), S126 - S133.

Sahin, M. A. and Yazicioglu, Y. (2017) “Intelligent control of electric wheelchair with obstacle avoidance”, Journal of Medical Systems, 41(11), 155 – 176.

Shahin, M. K., Alam, M. J. B., Hossain, M. I. and Rahman, M. M. (2017) “Relationship between Infrastructure and Economic Development: An Empirical Analysis”, Journal of Social Sciences Research, 3(9), 137 – 144.

Shibata, T., Tanie, K. and Yonemitsu, Y. (2001) “Development of an automatic guidance system for wheelchair robot”, Advanced Robotics, 15(5), 617 – 632.

Shittu, S. (2020) “Design and Development of a Three-Degree of Freedom Arm Robotic Manipulator for Wheelchair Users”, Robotics, 9(1), 1 – 14.

Simpson, R. C. (2005) “Smart wheelchairs: A literature review”, Journal of Rehabilitation Research and Development, 42(4), 423 – 436.

Singh, D. P. (2014) “Design and Development of Intelligent Wheelchair for the Physically Challenged and Elderly”, International Journal of Scientific and Research Publications, 4(4), 1 – 4.

Škraba, A. Stojanović, R., Zupan, A., Koložvari, A. and Kofjač, D. (2015) “Speech-controlled cloud-based wheelchair platform for disabled persons”, Microprocessors and Microsystems, 39(8), 819 – 828.

Srishti,M. K. (2015) “Empowering the physically challenged with electric wheelchairs”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 4(4), 2967 – 2973.

Umeh, K. (2016) “Assessment of Assistive Technology Needs of Individuals with Disabilities in Nigeria”, Disability, CBR & Inclusive Development, 27(2), 63 – 85.

Wang, T., Li, W., Zhou, C., Wu, W. and Zhao, J. (2020) “An ultrasonic distance measurement method independent of atmospheric conditions”, Journal of Physics: Conference Series, 1649, 012000 – 012013.

Webb, M. (2005) “Farnell Electronics Components limited”, Farnell Components”, Jerrold Printing, Norwich, pp. 1 – 125.

Winter, A. and Hotchkiss, R. (2025) “Mechanical Principles of Wheelchair Design”, Massachusetts Institute of Technology & Whirlwind Wheelchair International, pp. 1 – 37. United States, America. Available [Online]: HYPERLINK "https://web.mit.edu/awinter/Public/Wheelchair/Wheelchair%20Manual-Final.pdf" https://web.mit.edu/awinter/Public/Wheelchair/Wheelchair%20Manual-Final.pdf .

Zhou, J., He, Y., Xie, J., Chen, X. and Wang, Q. (2018) “Design of an electric wheelchair based on solar energy”, Journal of Physics: Conference Series, 1033(1), 012010 – 012018.